Removal of Arsenic (III) from water by Cerium hydroxylamine

A Dissertation
Submitted in partial fulfillment for the degree of

MASTER OF SCIENCE IN CHEMISTRY

BY

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UNDER THE SUPERVISION

OF

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DECLARATION

The work embodied in this report is an original Experiment carried out by the author, on the topic entitled ***"Removal of Arsenic (III) from water by Cerium hydroxylamine"*** *for partial fulfillment of degree in Master of Science (Chemistry), NIT Rourkela. To the best of my knowledge and belief, this work has not been submitted to any other University or Institution to confer any Degree or Diploma.*

Niharika Das

CERTIFICATE

This is to certify that the project report entitled, "***Removal of Arsenic (III) from water by Cerium Hydroxylamine***", is being submitted to National Institute of Technology, Rourkela by Ms Niharika Das, Roll number 410CY2006 for partial fulfillment of the Master of Science degree, Chemistry, which is an original work carried out under my guidance and supervision. This work has not been submitted by her for any other degree to any other Institution or University.

The present study is a valuable contribution for the advancement of knowledge in the field of material chemistry and its environmental application.

In habit and character Ms Niharika Das is quite a fit and proper person for the further research work.

I wish her all success in his future life.

Prof. R.K. PATEL
Department of chemistry
NIT-Rourkela

ACKNOWLEDGEMENTS

I would like at this moment to convey my sincere gratitude and thankfulness to Prof. Raj Kishore Patel, H.O.D Prof. Braja Gopal Mishra, Mr. Sandip Mandal, Department of Chemistry, NIT Rourkela for his constant encouragement and sustained guidance has made this project successful.

And above all, I would like to convey my gratitude towards my parents, my family and my friends for their consistent support and help to my work through me. If not, this project would not have come to existence.

Niharika Das

CONTENTS

ABSTRACT

Arsenic is potentially a carcinogenetic toxic material to human health. The acute lethal dose of arsenic to humans has been estimated to be about 0.6mg/kg/day. Irrespective of various other treatment technologies cerium hydroxylamine can be an efficient adsorbent for removal of Arsenic (III). In the present work, 0.7mg/L adsorbent dose of Cerium Hydroxylamine was treated with Arsenic sample at pH 7.0 in optimum temperature condition of (27±2ºC). The maximum removal of Arsenic found to be 99% as analyzed by AAS (Atomic Adsorption Spectrophotometer). Further characterization includes XRD, FTIR, SEM and EDAX. Batch study are carried out for initial concentration of 10 mg/L, 50 mg/L, 100 mg/L Arsenic (III) using optimum adsorbent dose of 0.7 mg/L having maximum removal 96-99% at pH 2-8 in contact time of 30 minutes with temperature 60^0C. The synthetic Arsenic concentration was initially 100 ppb. These studies report the result of an extensive investigation pertaining to arsenic removal properties of a hybrid sorbent and produce quality drinking water.

Key Words: Arsenic removal, hybrid material, adsorption, AAS.

2. INTRODUCTION

Arsenic is notoriously poisonous, semi-metal element. Its contamination in ground water is a problem that affects millions of people across the world causing discoloration and thickening of the stomach pain, skin, nausea, diarrhea, vomiting, numbness in hands and feet, blindness and partial paralysis. Arsenic may be present as one of several As(III) species (eg:-H_2AsO^{3-} and H_3AsO^3) and As(V) species (eg:- H_2AsO^{4-} and $HAsO_4^{2-}$) and also as an organ arsenical compound (eg:- Herbicides) or as an Arsenic complex with another dissolved or colloidal species (eg:- $FeHAsO_4$). At neutral pH, the most common form of Arsenic (III) and Arsenic (V) are H_3AsO_3 and $H_2AsO_4^-$ respectively. The EPA (Environmental Protection Agency) revised the drinking water standard to 10ppb; there has been great interest in technologies for removing Arsenic compounds from potable water supplies. EPA through its comprehensive study for evaluation of the cost and effectiveness of various Arsenic removal technologies has narrowed it to some specific range of methods. These methods/technologiesincludes: - chemical-precipitation methods, membranes, ion-exchange, forth floatation, solvent extraction, reverse osmosis, oxidation and adsorption.Adsorption is more specific for Arsenic removal than simple ion-exchange or membranes. The specific results from the formation of a chemical bond between the adsorbent and the Arsenic species are greater. The adsorption strength is pH dependent and there is still some competition for adsorption sites by other ions such as phosphate, silicate, sulfate and fluoride. However, there is a great attraction for methods used for removing both Arsenic (V) and Arsenic (III) compounds in water treatment plants which involves chemical-precipitation using iron and aluminum salts. A detailed description of the treatment processes is very essential for removing Arsenic to produce a healthy drinking water**.**

3. LITERATURE REVIEW:-

3.1 BACKGROUND

Water is typically referred to as polluted when it is impaired by anthropogenic contaminants and either does not support human necessities, such as drinking and/or undergoes a marked shift in its ability to support its biotic constituent, such as fish. Naturally occurring phenomena's such as volcanoes, algae blooms, earthquakes and storms also cause major changes in water quality and the ecological status of water. A few statistics illustrate the scale of the problem that waste water (chemicals washed down drains and discharged from factories) can cause. About half of the ocean pollution is caused by sewage and waste water. Every year, the world generates 400 billion tons of industrial waste, out of which maximum is pumped untreated into rivers, oceans, and other waterways. In the India alone, around 400,000 factories take clean water from rivers, and many polluted waters are pumped back in their place. However, major improvements have been carried out in waste water treatment recently.In water, the most common valence states of arsenic are As (V), or arsenate, which is more prevalent in aerobic surface waters and As (III) or arsenite, which is commonly found in anaerobic ground waters. The occurrence of arsenic in groundwater is mostly due to the leaching of geological materials, mineral precipitation,dissolution of unstable arsenic minerals, desorption- adsorption, occurrence of chemical transformation, input from pesticides, geothermal sources and fertilizers. Trivalent arsenic is the reduced state of inorganic arsenic, which is highly toxic pollutant in natural environments. It is highly toxic, soluble and mobilized than the oxidized state of inorganic arsenic, arsenate (As-V). The deleterious presence

of as in our environment is of great concern. Arsenic makes up 0.00058% of the total mass of the Earth's crust. Drinking water concentration in excess of 0.05mg/l is detrimental to human health. Arsenic poisoning in West Bengal drinking tube well water was first reported in 1980. Long-term ingestion of arsenic contaminated water may cause keratosis, hyper pigmentation on the palms of the hands and soles of the feet, skin cancer, black foot disease (a severe form of peripheral vascular diseases that leads to vast changes), bone marrow depression, cardiovascular disease and so on. Cirrhosis is caused by Arsenic toxicity to liver. The problem of arsenic poisoning is now a global issue. In degree of calamity terms, Bangladesh comes first, followed by West Bengal, Cambodia and Vietnam. Around 150 million people may be at risk in West Bengal and Bangladesh alone. In all these areas, arsenic occurs in deltaic alluvial sediments constituting the shallow aquifers.

3.2 Sources of Arsenic (III) in India

(A) Groundwater:-

Natural arsenic contamination in groundwater occurs in diverse geological conditions; in unconsolidated sediments and in sedimentary, igneous and metamorphic rocks with a huge range of ages. However, most of worst cases are found in tropical river basins of Asia, especially in deposits of river draining young mountain ranges, where sandy aquifers are interbedded with silts and peats. Arsenic pollution is found in climates ranging from the hot and humid tropics, to arctic Alaska and hyper arid deserts. Despite this diversity, in any given location, Arsenic contamination usually has a well defined relationship to particular geological units and hence to particular depths of wells. Under natural conditions, the greatest range and the highest concentrations of arsenicare found in groundwater as a result of the strong influence of the water–rock interactionsand the favorable physical and geochemical conditions in aquifers for the accumulation and mobilization of arsenic. Arsenic mobilization is particularly at pH values typically found in groundwater (pH,

6.5–8.5) under oxidation and reduction conditions. Background concentrations of arsenic in groundwater in most countries are less than 10 μg/L and sometimes substantially lower. However, literature values show a very wide range, from < 0.5 to 5000 μg/L. Most high level arsenic in groundwater are the result of natural occurrences of arsenic. Most of the Arsenic pollution cases caused by mining are numerous but tend to be minimized. Under oxidizing conditions, arsenate is dominant, as the H_2AsO^{4-} form at low pH (less than approximately 6.9), or as the $HAsO_4^{2-}$ form at higher pH. Due to reduction conditions at pH less than approximately 9.2, the uncharged arsenite species H_3AsO_3predominates .In an extensive groundwater survey of USA, Welch *et al*. (2000) reported that approximately half of the 30,000 samples analyzed had naturally occurring arsenic levels≤ 1 μg/L, with about 10% exceeding 10 μg/L. Geothermal water and highly evaporating rates are associated with arsenic concentrations ≥ 10 μg/L in ground- and surface waters. As arsenic is a global problem. Atleast 130 million people across the globe have been, or are exposed to, levels of arsenic in their drinking water exceeding the WHO limit of 10ppb.

(B) Air:-

Concentrations of arsenic in ambient air in remote locations range from less 1 to 3 ng/m3, but cities concentration may range up to 100 ng/m3. Ambient air of Arsenic is usually a mixture of arsenite and arsenate, with organic species composed of negligible importance except in areas of arsenical pesticide application or other industrial activity (WHO, 2001). Arsenic-based mining, pesticides and smelting, manufacturing and waste-disposal activity are sources of arsenic in air. Introduction of Arsenic into the atmosphere directly from these processes or it may be resulted from sediment and soil particles being entrained into the atmosphere or the production of volatile arsenic metabolites, such as arsines, from soils.Defining what constitutes natural levels is, therefore, difficult. In the atmosphere, existence of arsenic as particulate matter, mostly less than 2

μm indiameter. These particles are transported by air currents until they return to the groundvia wet or dry deposition, where a certain amount of suspension may occur.

However, an early occupational study suggests that 23per cent of particles in samples of arsenic-polluted air were greater than 5.5μm. Annual average concentrations ofarsenic in urban and ruralareasin the range of 5 - 10 and 1 - 5 ng/m^3respectively, The World Health Organization (WHO) (2000) suggestsconcentrations of arsenic range from 1 - 10 ng/m3 in rural areas, 3 - 30 ng/m3 in non-contaminatedurban areas, and can exceed 1 μg/l near emission sources . Schroeder *et al*. (1987) also reported 0.007 - 1.9 ng/m3 concentration of arsenic in remote areas, 1 - 28ng/m3 in rural Locations and 2 – 2320 ng/m3 in urban environments, with the highest concentrationsoccurring in the vicinity of non-ferrous-metal smelters.

(C) Others

Arsenic has been detected in rainwater at concentrations less than 0.005 to 45 μg/L, with higher concentration occurring in contaminated areas (WHO, 2001). Arsenic compounds are abundant in certain seafood's at concentrations as high as several hundred milligrams per kilogram. Although Arsenic is found in many marine animals, most watery species contain arsenic as the major arsenical compound. Arsenic is not metabolized by humans and is believed to have low or negligible toxicity. Inorganic arsenic and arsenic contained sugars can, however, be present in some marine algae, seaweeds, oysters, mussels and clams. Arsenite and arsenate are also commonly found in fungi. In Bangladesh, contamination of agricultural soils from long-term irrigation with arsenic-contaminated groundwater led to phyto-accumulation in food crops. In WestBengal (India), high arsenic contents have also been reported in many agricultural products and spices, especially in the skin of most vegetables, as a result of the dependence on groundwater .High levels of arsenic have also been reported in plants and cow's milk, as a result of heavy contamination of soils, surface and groundwatersby arsenic attributed to industrial sources

(veterinary chemicals, pharmaceuticals, pesticides industries) in the area of Patancheru, Andhra Pradesh (India).

3.3 Human exposure of arsenic:-

The naturally anthropogenic occurrence of arsenic in drinking-water has been recognized as a major public health issue in various regions of the world over the past decades. Areas affected by arsenic across the globe, and significant contamination have been identified in Bangladesh, West Bengal and many more countries around the world. As contamination in drinking water is of concentration 5microngram/liter, Arsenic in drinking water has been reviewed by WHOand provided a guideline of 10microngram/liter after concluding that arsenic in inorganic form is carcinogenic to human and that the main exposure is through drinking water and food. The effect on human exposure which is caused by arsenic is in panel assessment.These effects were dependent on duration and dose of exposure. It was also concluded that there were evidence for bladder and lungs cancer with ingestion of inorganic arsenic through drinking water.One of the principle pathways of exposure of arsenic is contamination through ground water.From several regions of world elevated concentration has been reported. Arsenic contamination is maximum in ground water than surface water which has been extensively used by humans.


4. AIMS AND OBJECTIVE OF THE EXPERIMENT:-

- The principal aim of this thesis is to generalize the purpose of the synthetic material.
- To characterize the synthetic material and give relevant data required for removal of Arsenic (III).
- To classify the batch study and various analyses carried out at optimum condition suitable for removal.
- The effective role of adsorbent needed for maximum Arsenic removal.
- The methods used for removal processes should be less cost effective than the methods used by various other Authors.
- To minimize the concentration of Arsenic (III) and produce quality drinking water.
- To classify kinetic study and thermodynamics stability.
- Finally, the excessive removal of As^{3+} ions in presence of other competitive ions.

5. EXPERIMENTAL SECTION

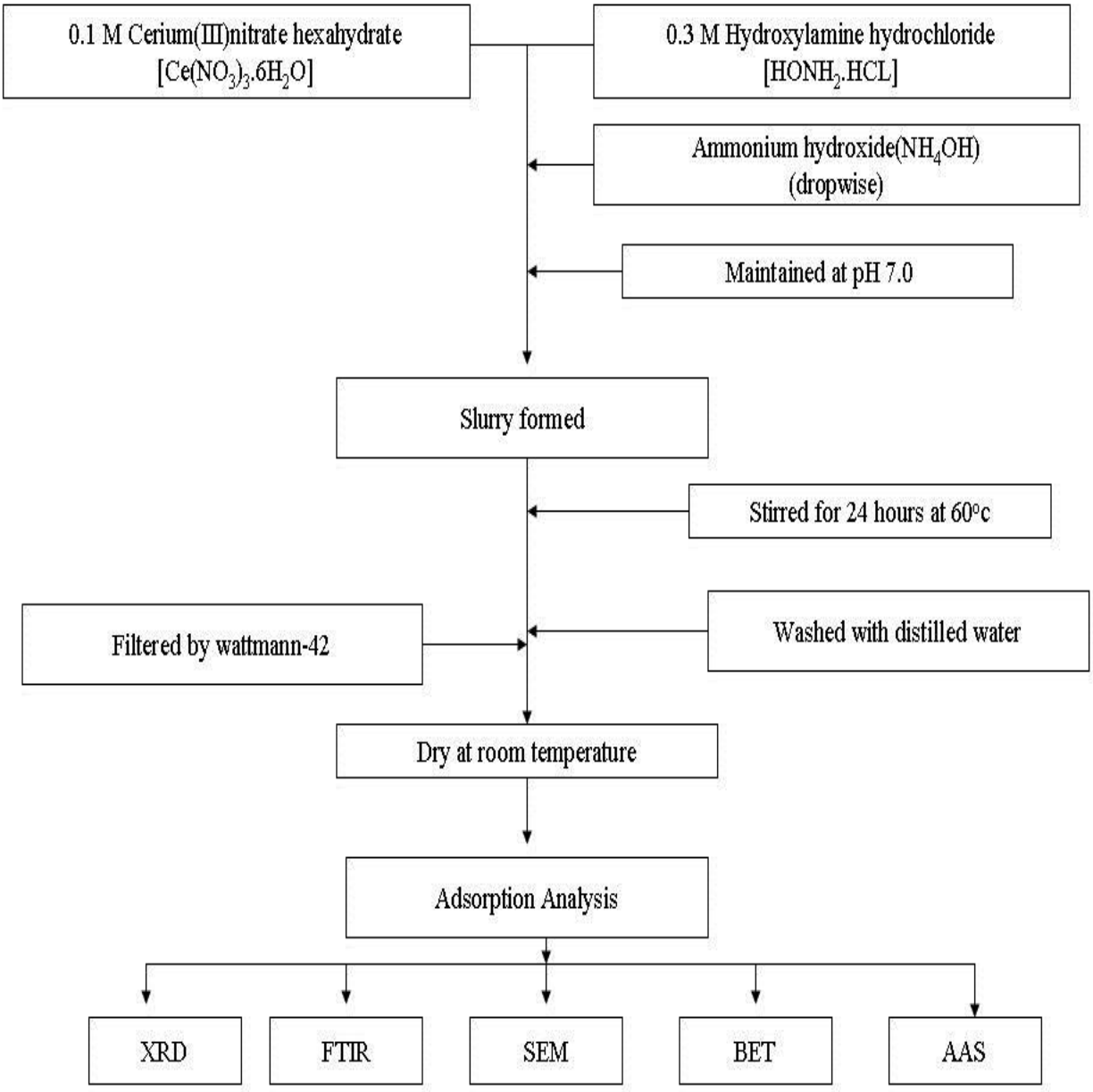
5.1. Materials and Methods

AR grade chemicals have been used for the study of Arsenic removal. Borosil and tarson glass wares have been used like measuring cylinder, volumetric flask, conical flask, etc. Cerium nitrate [Ce $(NO_3)_3.6H_2O$] and Hydroxylamine hydrochloride [$HONH_2$.HCL] were used for the synthesis of the hybrid material. Standard solution of arsenic (III) was prepared from sodium arsenite (Na AsO_2). HCl and Ammonium Hydroxide (NH_4OH) varying the pH. The different instruments used for the study are pH meter (Elico), AAS (Perkin Elmer PE Analyst Atomic Absorption Spectroscopy), XRD (Phillips Powder Diffract meter Model PW 1830), SEM (JEOL, jXA-8100).

5.2. Synthesis of Cerium Hydroxylamine

A sample of cerium hydroxylamine were prepared by adding 0.1M [$Ce(NO_3)_3.6H_2O$] solution in 0.3M [$HONH_2$.HCL] solution of a (1:3) mixture and Ammonium Hydroxide [NH_4OH] solution drop wise with constant 24hr stirring in a 500ml borosil beaker. The resulting slurry obtained was then filtered and washed several times with distilled water. On drying at room temperature it resulted into a yellowish white porous powdered material. It was then crushed into finely powdered form and was then stored in air tight container and was used for further studies.

Figure.1 Flow chart for synthesis of cerium hydroxylamine:-



6. *Result and discussion*

6.1 Characterization of Cerium hydroxylamine hybrid material

The present study is an effort to explore synthesis of Cerium hydroxylamine and its application for the removal of trivalent arsenic (As III) from contaminated aqueous solution. The material is characterized based on the data of analysis of SEM, XRD, FTIR, UV-VIS, CHNS, The chemical analysis of the material is presented in (Table 1.) the material forms a matrix. The chemical stability of the material was identified when kept in 20 mL of different mineral bases, acids and salt solutions of different concentration for 24h and the supernatant liquid was examined for cerium(Table 2). A high chemical stability exposed by material was found that the material was quite stable in most of the mineral acids and salt solutions.The main physicochemical parameters of the contaminated waterare listed in (Table 3).

Table- 1: Chemical properties of present Ce-HA hybrid material

	N%	*C%*	*H%*	*S%*
Ce-Hydroxylamine Hybrid Material	0.1034423	1.53603327	0.65118974	0.08530691

Table-2: chemical stability of the Ce-HA hybrid material

Solvent (50 mL)	Stability
1M H_2SO_4	Soluble
2M H_2SO_4	Soluble
4M H_2SO_4	Soluble
1M HNO_3	Insoluble
2M HNO_3	Insoluble
4M HNO_3	Soluble
1M HCL	Insoluble
2M HCL	Insoluble
4M HCL	Soluble
1M NaOH	Insoluble
2M NaOH	Insoluble
4M NaOH	Insoluble
1M NH_4OH	Insoluble
2M NH_4OH	Soluble
4M NH_4OH	Soluble

Table- 3: shows the main physicochemical parameters of the contaminated water

Mg^{2+}	*55.23 mg/L*
Ca^{2+}	*121.81 mg/L*
TH(Total Hardness)	*176.44 mg/L*
COD	*14.33 mg/L*
TOC	*0.002 mg/L*
Cl^-	*61.45 mg/L*
Fe^{3+}	*0.12 mg/L*
SO_4^{2-}	*73.55 mg/L*
NO_3^{2-}	*3.71 mg/L*
F	*0.006 mg/L*
Hg^{2+}	*NIL*
Cd^{2+}	*0.004 mg/L*
Cr (VI)	*0.03 mg/L*
Al^{3+}	*0.02 mg/L*
Pb^{2+}	*NIL*
As^{3+}	*NIL*
Cu^{2+}	*0.02 mg/L*

6.1.1 SEM micrographs of Cerium hydroxylamine material

The surface morphology of the material is studied by Scanning electron microscopy (SEM) is presented in (Figure 2). The SEM comparison is done between fresh hybrid material and loaded trivalent arsenic hybrid material to better accepting of the change in the surface morphology; from Figure 2a i.e. Before adsorption the material is porous. From figure 2b i.e. after adsorption it is clear that the trivalent arsenic ions adsorbed on the surface and the surface covered with white color nodules. Further Energy dispersive X-ray spectroscopy (EDAX) is done to get the final confirmation of arsenic adsorption on the surface of the hybrid material represented in (Figure 2).

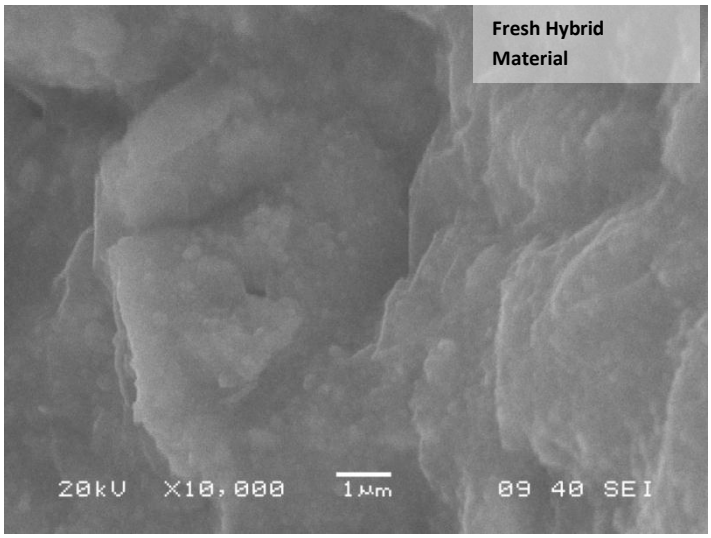


Fig 2a.SEM analysis before adsorption

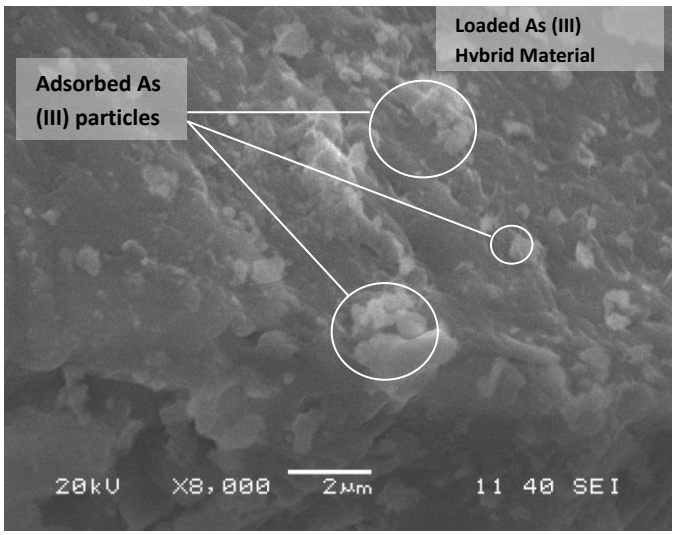


Fig 2b. SEM analysis after adsorption

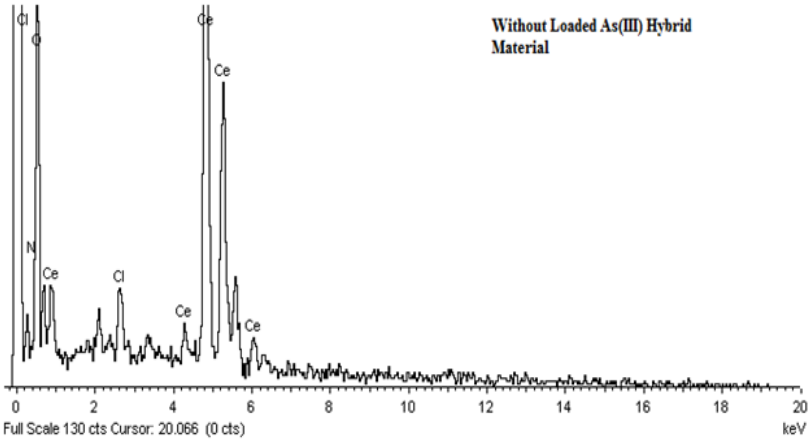


Fig 3. EDAX of CeriumHydroxylamine material

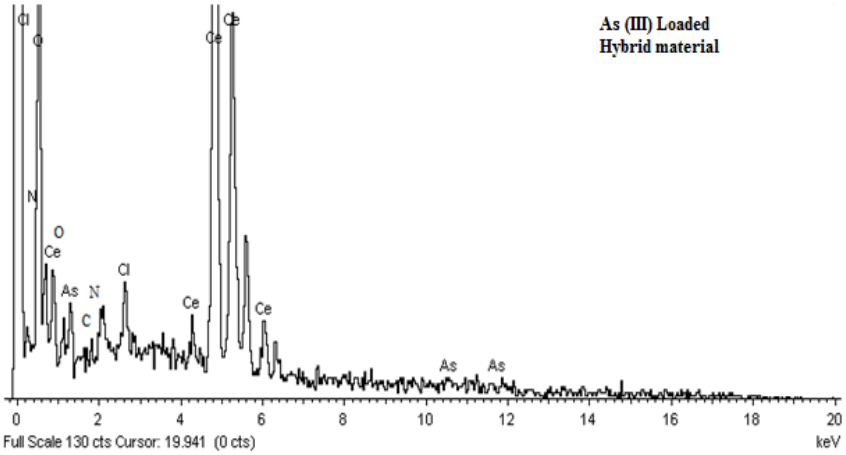


Figure 4: EDAX analysis of the CE-HA hybrid material before adsorption and after adsorption

6.1.2 BET study:

BET surface area study of the material is done through nitrogen adsorption technique and it is found that the material is having a high surface area (Table 4), the specific surface area of the material is not incorporated because the results of the analysis are awaited.

Table-4: BET-Isotherm report of the hybrid material

Property	Method	Ce- Hydroxylamine Hybrid Material
Specific surface area (m^2/g)	Nitrogen adsorption	Result awaited
Pore Volume (Cm^3/g)	Nitrogen adsorption	Result awaited
pore diameter	Nitrogen adsorption	Result awaited

6.1.3. XRD study

Powdered XRD of the material was obtained by using PHILIPS X'PERT X-Ray Diffractometer with Cu kα radiation(35 kv and 30 mA) at a scan rate of 20/min and was analyzed using standard software provided with the instrument. The XRD pattern of the sample is presented in (Figure. 5); Sharp peaks were obtained indicating the sample was crystalline. XRD was analyzed using standard software but a very intense peak of cerium hydroxylamine with a d-spacing of 3.13079 [A^O] at, 2 theta 38.50 ^{o} is found and volume of the cell is 160.20, before adsorption it is supported by the JCPDES file number 64-0507.

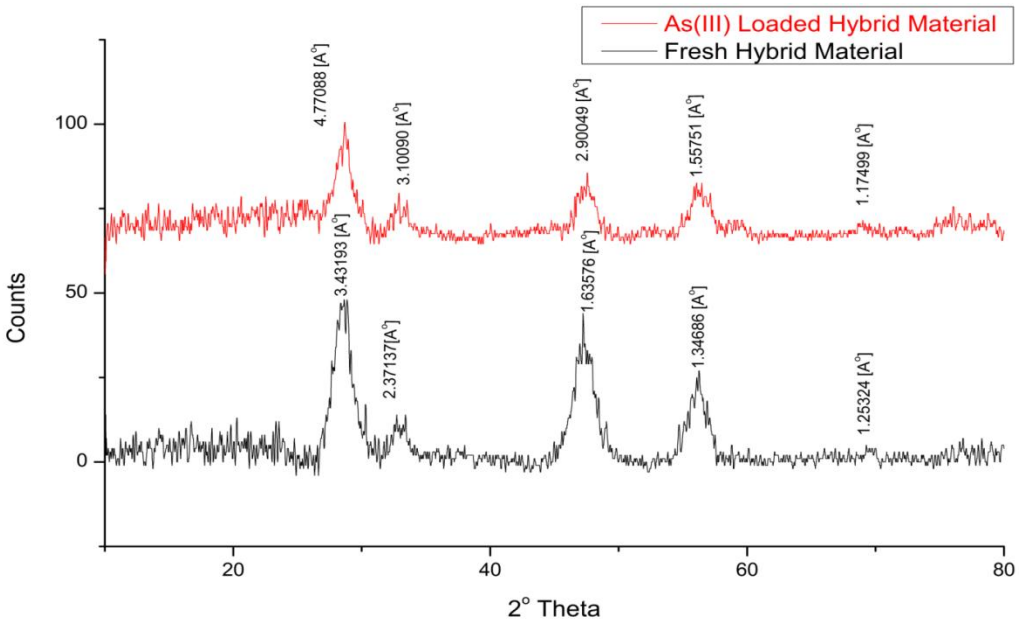


Figure 5: XRD patterns of the CE-HA hybrid material before adsorption and after adsorption

6.1.4. FTIR study

FTIR study of the sample was carried out (Figure. 6) in order to know the presence of different groups and structures in the material. The presence of band at 3356.10 cm^{-1} is due to bonded OH groups, NH stretching, which indicates the presence of water of crystallization. Further, the presence of a peak at 2934.14 cm-1 in cerium hydroxylamine hybrid material is due to the

presence of Aliphatic C-H groups and NH bending. This peak is found to be shifted with slight broadening after adsorption at 2923.21 cm^{-1}, which is an indication of bonding of the arsenite anion (CrO_4^{2-}). The peak at 818.19 cm $^{-1}$ and 510.15 cm $^{-1}$ in cerium hydroxylamine is assigned to metal- oxygen bonding is further shifted after adsorption towards 828.96 cm-1 and 505.91 cm^{-1}

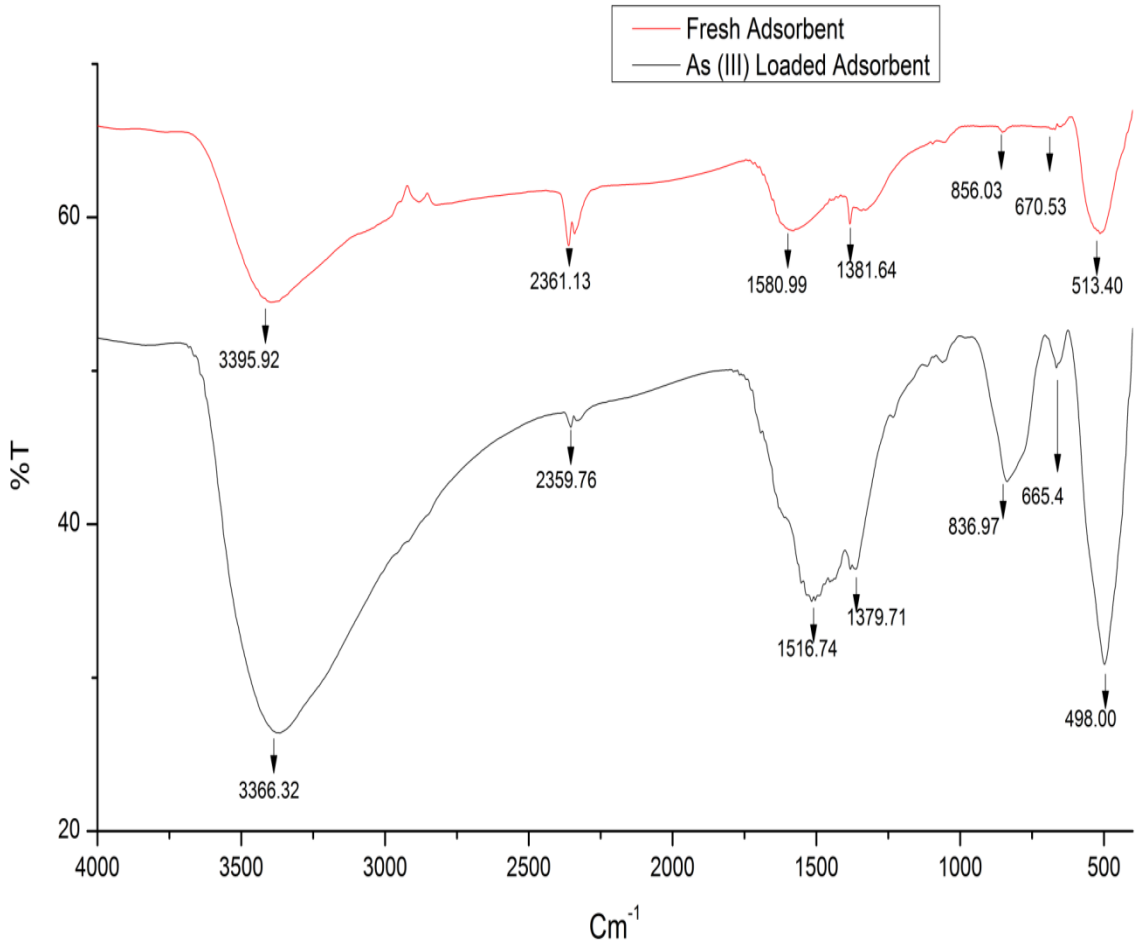


Figure 6: FTIR pattern of CE-HA hybrid material before adsorption and after adsorption

6.1.5 Particle size analysis of the hybrid material

Particle size of the hybrid material is done by Malvern nano ZS 90, the particle size of the material was found to be 208.7 nm.

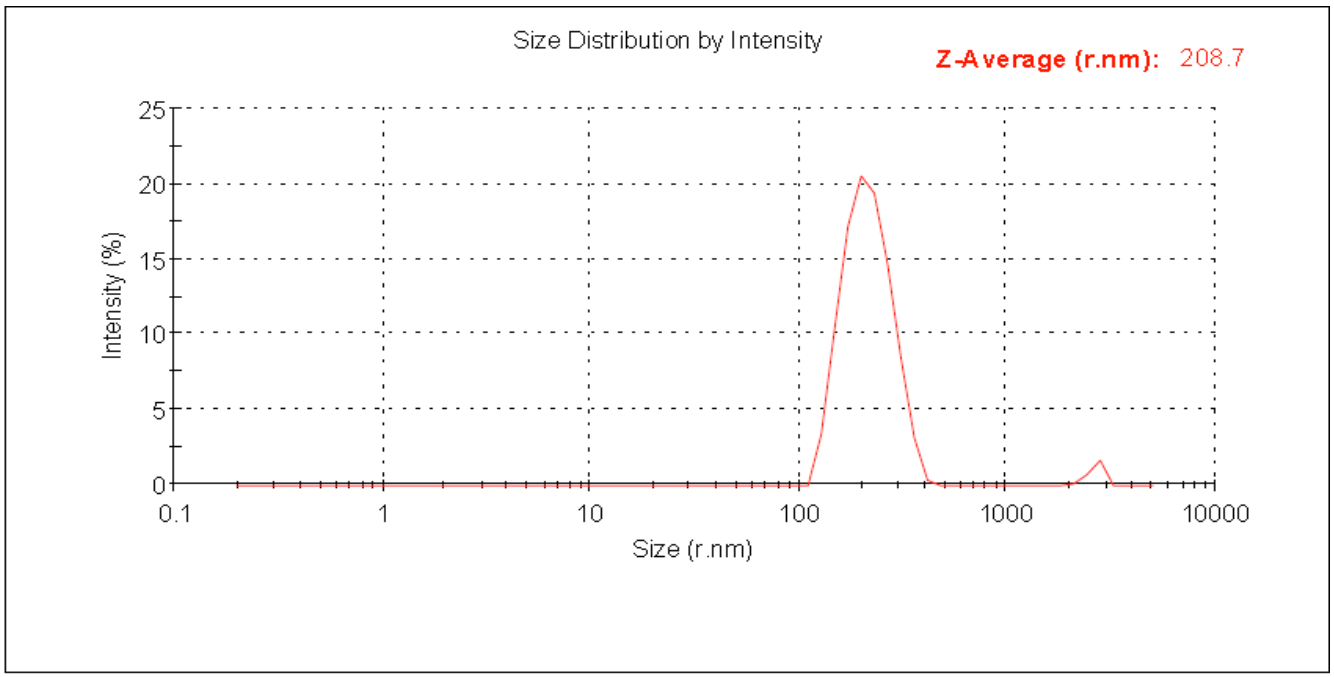


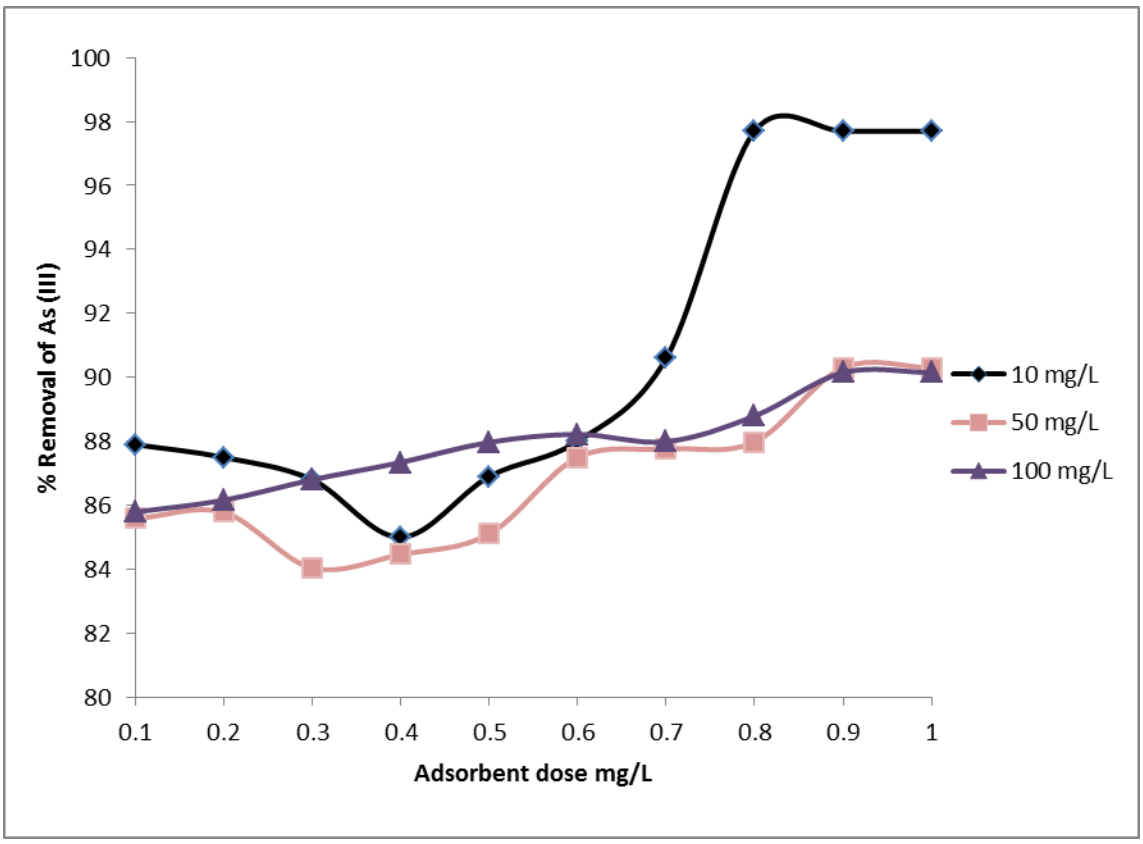
Figure 7: particle size of the CE-HA hybrid material

6.2 Batch Study of the hybrid material

6.2.1. Effect of Adsorbent Dose

The effect of adsorbent dose on the removal of Arsenic (III) is investigated in neutral condition (pH 7), at ambient temperature (27±2 ^{o}C) and contact time of 30 minute for initial Arsenic (III) concentration of 10mg/L, 50mg/L and 100mg/L. The results are presented in (Figure 8). It is evident from the (Figure 8) that the removal of Arsenic (III) increases from 88.56 to 96.33 %, 92.89 to 99.33% and 90.78% to 97.93% for 0.1 – 1.0 g/ 10ml of cerium hydroxylamine hybrid material respectively with initial Arsenic (III) concentration of 10mg/L, 50mg/L and 100mg/L. It is observed that after dosage of 0.7mg/L, there is no significant change in percentage of removal of Arsenic (III). Due to the overlapping of active sites at higher dosage. So, 0.7mg/L is considered the optimum dose and is used for further study.

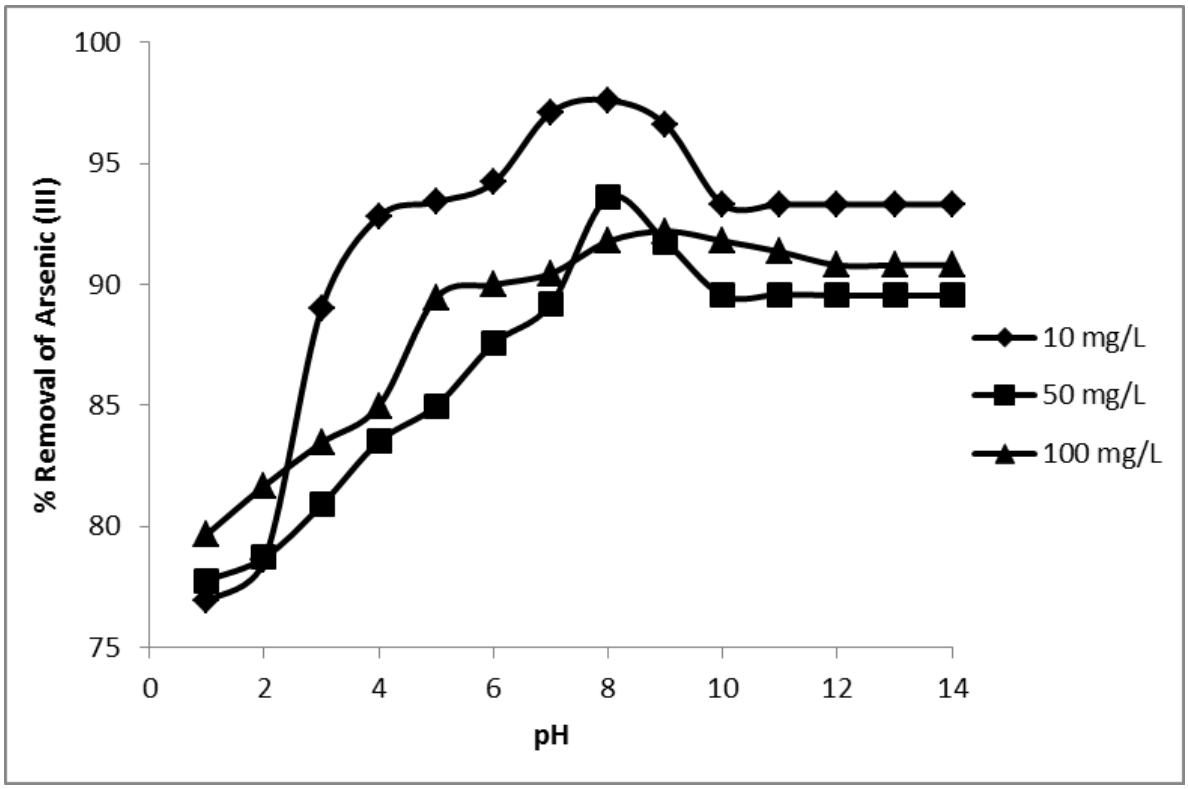
Figure 8: Effect of adsorbent dose on the removal of Arsenic (III) from the hybrid material



6.2.2. Effect of pH

Percentage removal of Arsenic (III) at different pH is studied in batch experiments using 0.7 mg/L, at ambient temperature (27±2 ^{o}C), contact time of 30 minute for initial Arsenic (III) concentration of 10mg/L, 50mg/L, and 100mg/L. The results are presented in (Figure 9). The pH of the solution after adsorption is measured and is found to increase or decrease slightly without any regular trend. It is evident from the graph that there is removability at pH 2 and to pH 8 almost 93.1 % removal and the highest removal was achieved at pH higher than 5 but below 8. This decrease of Arsenic (III) uptake at alkaline pH could be due to competition for active sites by excessive amount of hydroxyl ions.

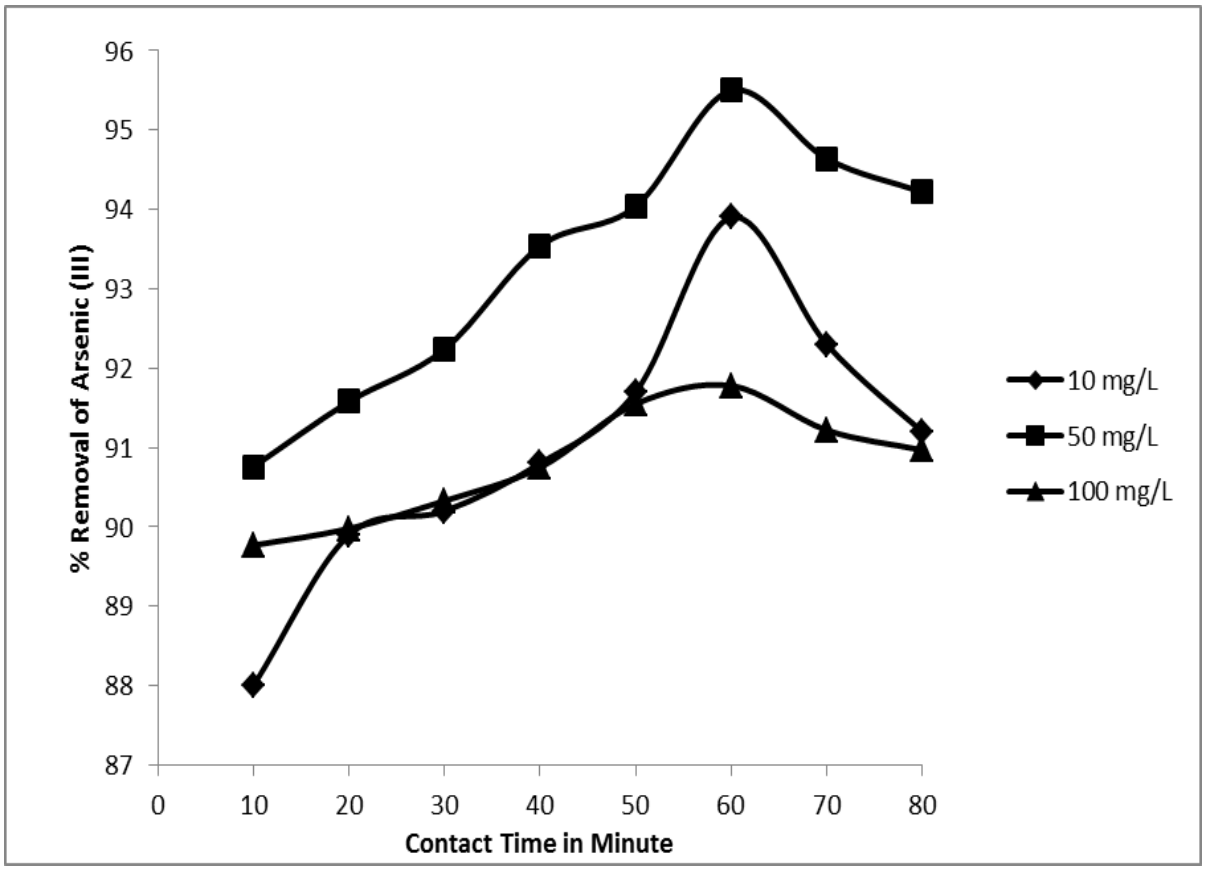
Figure 9: Effect of pH on the removal of Arsenic (III) from the hybrid material



6.2.3. Effect of contact times

Batch study of Arsenic (III) at different contact time is studied for initial Arsenic (III) concentration of 10mg/L, 50mg/L and 100mg/L at pH 7 and adsorbent dose of 0.7 mg/L keeping all other parameters constant. The result is represented in (Figure 10). It is clear from the (Figure 10) that more than 86 % removal takes place within 60 min and equilibrium is reached after 60 min. The transformation in the rate of removal might be due to the fact that initially all adsorbent sites are unoccupied and also the solute concentration gradient is high. Later the uptake rate of Arsenic (III) by adsorbent is decreased suggestively, due to the decrease in the number of adsorption sites as well as hexavalent concentration.

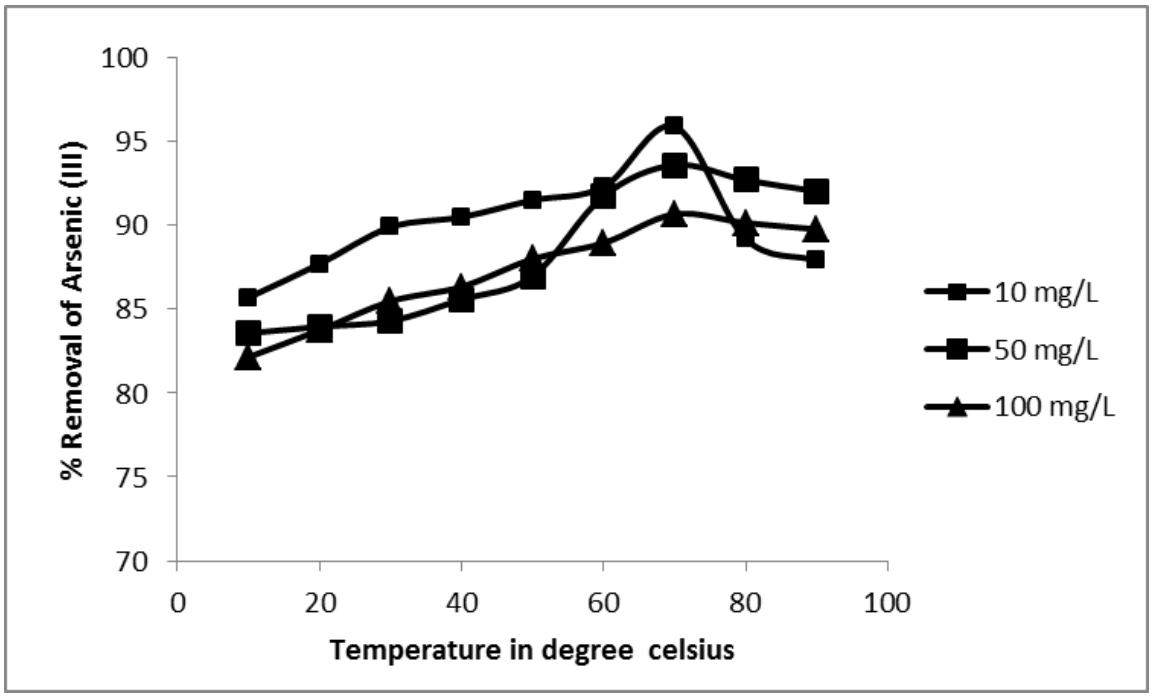
Figure 10: percentage removal of Arsenic (III) from the hybrid material contact time



6.2.4. Effect of Temperature

The consequence of temperature on the adsorption of Arsenic (III) with initial concentration 10mg/L, 50 mg/L and 100 mg/L is studied using optimum adsorbent dose 0.7 mg/L and at contact time of 30 minutes. The results are represented as percentage removal of Arsenic (III)) versus temperature (Figure 8). The percentage removal of Arsenic (III) with initial concentration10mg/L, increased from 85 % to 91.25 %, for 50 mg/L, increased from 85.05 %to 95.04 % and for 100 mg/L, increased from 83.58 % to 87.38% for 25 to 45° C temperatures respectively. From the (Figure 11) that, at the temperature between 50^{o} Celsius to 60^{o} Celsius the removal was almost 91 % and with increase in temperature the percentage removal increase slowly and reached almost 88 % these happens due to collapsing of the active sites available for adsorption.

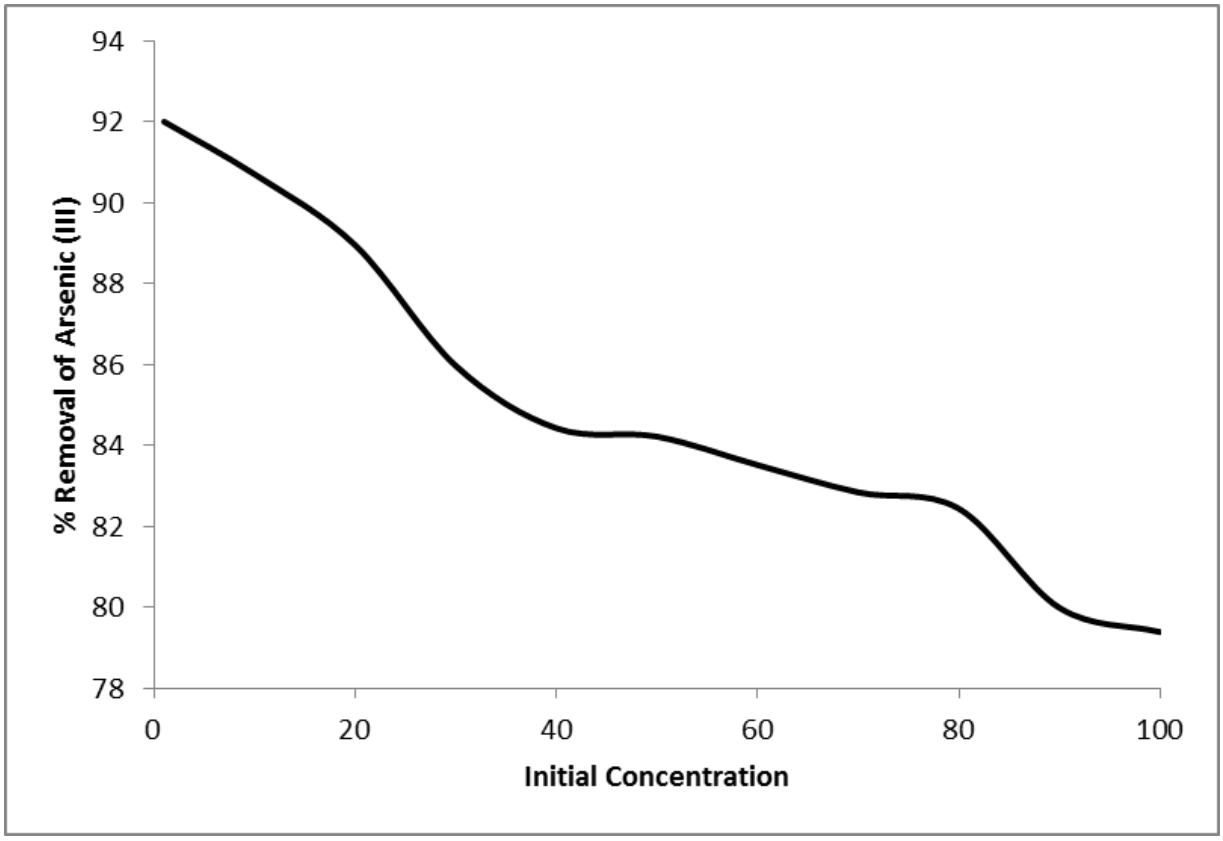
Figure 11: Effect of temperature on the removal of arsenic (III) from the hybrid material.



6.2.5. Effect of initial trivalent arsenic concentration

The adsorption of Arsenic (III) onto hybrid material is calculated by varying initial Arsenic (III) concentration using optimum adsorbent dose 0.7 mg/L at ambient temperature (27±2 ^{o}C) and contact time of 30 min. The results are signified in graphical form as percentage removal versus initial Arsenic (III) concentration in (Figure 12). The initial Arsenic (III) concentration is increased from 10mg/L to 100 mg/L and the corresponding removal gradually decreases from 91% to 87%. It is observed from the (Figure 12) that, there is a decrease in removal percentage with increase in initial Arsenic (III) concentration due to the fact that at greater adsorbate concentration, the free sites available approaches overload.

Figure 12: percentage removal of Arsenic (III) from the hybrid material versus initial arsenic (III) concentration



7. Conclusion

From the batch experiment it was concluded that the adsorbent dose was effective for removing Arsenic (III). The SEM and EDAX data confirmed the adsorption of arsenite anion on the surface of cerium hydroxylamine hybrid material. A further study of FTIR indicates bonding of Arsenite anion at 2923.21 cm^{-1} in hybrid material. The removal efficiency was 99% at pH 5. The optimum temperature required for removal process was 50-60^{o}C and adsorption time was found to be 60 min at 0.7 mg/L of adsorbent dose. These studies conclude the effective removal of Arsenic from the sample which is less cost effective and highly efficient.

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